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EFFECT OF ALUMINUM ON THE PROPERTIES OF CHROMIUM-NICKEL STEEL

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16. Abstract

A systematic study was made of the properties of chromium-nickel steel containing various amounts of aluminum. The experimental conditions are described. It is found that an aluminum alloy increases creep resistance and thermal resistance.

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EFFECT OF ALUMINUM ON THE PROPERTIES OF CHROMIUM-NICKEL STEEL

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At the present time, for work at high temperatures wide use is made of alloys with an iron base and containing large amounts of nickel and chromium. This can be explained by the fact that the alloys in question possess high scaling and creep resistance. However, the high cost and scarcity of nickel makes very real the problem of creating alloys which contain no nickel or a reduced amount of it, and which at the same time possess properties adequate for work at high temperatures.

The positive role played by aluminum in raising the heat resistance of chromium-nickel steel is well known. However, the introduction of large amounts of aluminum can lead to the formation of ferrite and to a worsening of the mechanical properties of steel. One may assume that there is an optimal amount of aluminum whose introduction into alloys will significantly raise their heat resistance and reduce very little their mechanical properties. In this connection, a systematic study was made of the combination of properties of chromium-nickel steel containing various amounts of aluminum. Based on [1], as a base we selected steel containing 18% chromium, nickel 14% and carbon 0.3%. In the cast state, it had an austenitic structure with inclusions of

* Numbers in margin indicate pagination in original foreign text.

chromium carbide along the grain boundaries. The aluminum content in the alloys varied from 0% to 7% at the expense of iron.

The alloys were melted in an induction furnace in a basic crucible. As charging material we used armco-iron, nickel N1, chromium 0, aluminum AV000. Carbon was introduced into the alloy through the addition of previously carburized armco-iron containing 3.4% carbon.

We studied hardness, strength, percentile elongation, impact strength, creep resistance, thermal resistance and relative increase in length after cyclic thermal treatment (CTT).

During testing for elongation at room temperature, case samples with a diameter of 6 mm and working length of 30 mm were used. The elongation rate amounted to 20 mm/min. At a temperature of 900° C, tests were conducted on cast samples with diameter of 5 mm and working length of 25 mm when the elongation rate was 4 mm/min.

For the tests of impact strength, the samples were square, 10 mm on a side, with a groove.

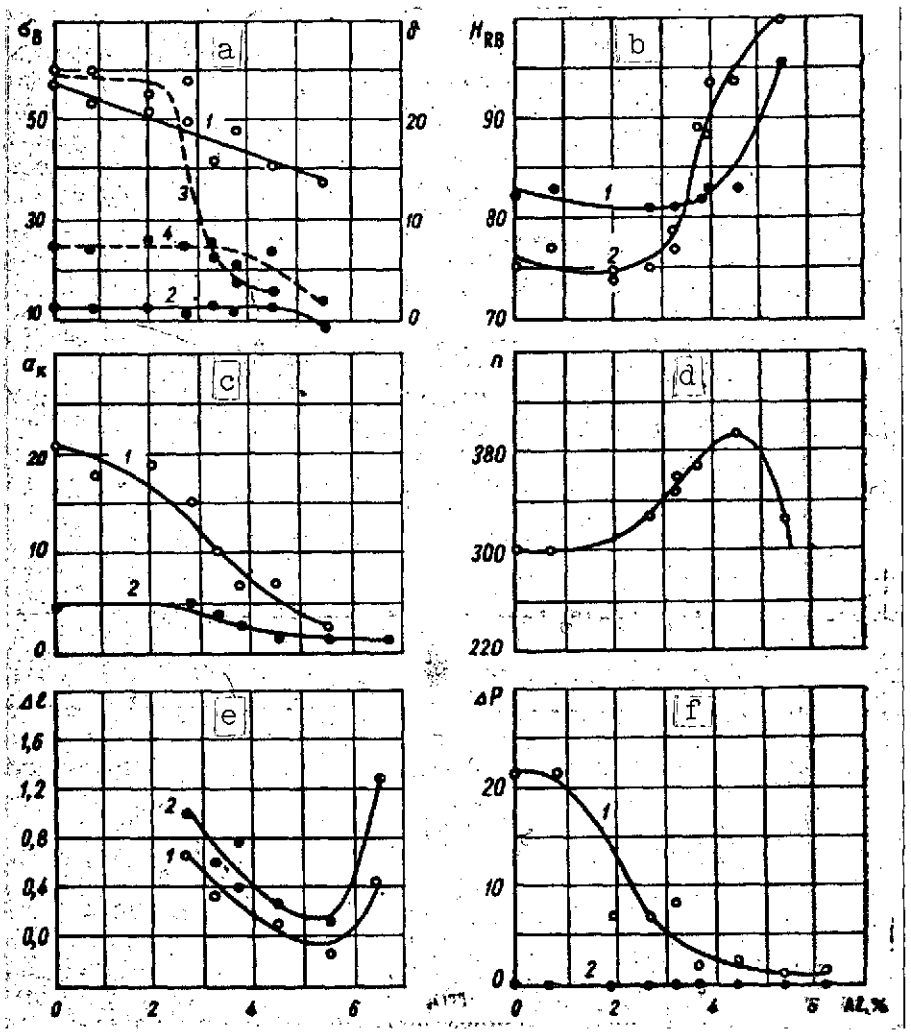
Thermal resistance was evaluated by the number of cycles of heating and cooling necessary for the appearance on the samples of visually apparent cracks. Cylindrical samples of 5 mm diameter were tested in stressed state, and they were heated by passing an electric current through them.

The relative increase in length of the samples was determined after a definite number of periodic heatings to 900° C in /101 an electric furnace, followed by cooling in cold water. The samples were square, 12 mm on a side and a length of 150 mm.

The results of tests of the properties of the alloy investigated are presented in Figure 1.

Clearly (Figure 1, a) the strength of the alloys at room temperature continuously decreases as the aluminum content increases, while the elongation falls to low values when the concentration of aluminum changes from approximately 2.5% to 3.5%. This change in the given samples is produced by the increase in the structure of carbides and then by the formation of the intermetallide NiAl (β-phase) and the strongly alloyed ferrite [1]. At a temperature of 900° C, the strength and relative elongation of the alloys is practically unchanged when /102
the concentration of aluminum increases up to 4.5%, and only when the aluminum content rises above the indicated limit does one notice some reduction in these properties.

Hardness of alloys in the cast state (Figure 1, b) is preserved at approximately the same level for an aluminum content up to 4% and then it rises sharply with a further increase in the concentration of aluminum. The hardness of alloys changes in a similar fashion when they are subjected to cyclic thermal treatment comprising periodic heating to 900° C, followed by cooling in cold water. The difference here lies solely in the sharp rise in hardness observed for lower concentrations of aluminum, and, in addition, the fact that the hardness of samples after cyclic thermal treatment with lower concentrations of aluminum has lower values than in the cast state. The sharp increase in hardness for specified aluminum concentrations is probably principally connected with the formation of crystals of the intermetallide NiAl in a finely dispersed state. Cyclic thermal treatment results in a more complete separation of the phases in question from α- and γ- solutions, and therefore the sharp growth of hardness in this case begins when there is a lower concentration of aluminum than in the cast state. When the concentration of



Effect of %Al content on the properties of chromium-nickel steel: a- strength δ_B, kG/mm^2 (1- at 20° C; 2- at 900° C) and relative elongation δ, % (3- at 20° C; 4- at 900° C); b and c- hardness H_{RB} and impact strength a_k, kG/cm^2 (1- in cast state; 2- after cyclic thermal treatment); d- thermal resistance n, cycles; e- relative increase in length Δl % (1- after 100 cycles; 2- after 200 cycles); f- creep resistance ΔP, G/m^2· hr. (1 - at 1100° C; 2- at 900° C)

aluminum is small, cyclic thermal treatment leads only to a more uniform condition of the alloys and consequently to some reduction in their hardness.

With an increase in the aluminum content, the impact strength of the alloys in the cast state is continuously lowered (Figure 1, c). Cyclic thermal treatment results in a reduction of the impact strength, and the lower the concentration of aluminum, the greater the reduction. The impact strength of the samples is preserved at the same level after cyclic thermal treatment for aluminum contents up to ca. 3%, and only when there is a further increase in the concentration of aluminum is there a gradual reduction, which is connected with the separation of crystals of the β-phase out of the γ- and α- solid solutions.

The thermal resistance of the alloys when they are alloyed with aluminum varies according to a curve with a maximum which is located near 5% aluminum (Figure 1, d).

The curves for the change of the length of the samples in the process of cyclic thermal treatment as a function of the concentration of aluminum is the mirror image of the curve of thermal resistance (Figure 1, e). The sharp drop in thermal resistance and the growth in the length of samples in the process of cyclic thermal treatment when the aluminum content is greater than 5% is connected with the embrittlement of the alloys.

Alloying the alloys with aluminum significantly increases creep resistance (Figure 1, f). When the aluminum content is 2%, there is a sharp drop in weight when the sample is kept in the furnace in an atmosphere of air for 100 hrs. at 1100° C.

Thus it has been established that alloying with aluminum those alloys which are based on chromium-nickel increases significantly their creep resistance and their thermal resistance, and facilitates stability of size in the process of cyclic thermal treatment. At the same time, at suitable aluminum contents the alloys maintain impact strength at an adequate level — which is very important when they are used as refractory materials in thermal furnaces.

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